TECHNOLOGY AND IMPLEMENTATION OF THE DUPIC CONCEPT FOR SPENT NUCLEAR FUEL IN THE ROK

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ABSTRACT

In order to maintain continuous g rowth of the nuclear power industry in Korea, several issues such as spent nuclear fuel management, safety of nuclear reactor and non-proliferation concerns, etc. should be kept in mind. Taking advantage of the Korean nuclear reactor strategy of having both light water reactors(PWR) and heavy water reactors(CANDU) for electricity generation, DUPIC(Direct Use of spent PWR fuel in CANDU reactors) nuclear fuel cycle concept has been suggested as one of the solutions of PWR spent fuel management, while improving the utilization of uranium resources in a proliferation-resistant way.

The DUPIC fuels for CANDU reactors can be refabricated by only mechanical and thermal processes without any separation of sensitive nuclear materials, even fission products, because the remnant fissile contents in the PWR spent fuel is high enough to be reused in CANDU reactors.

Major challenges for the DUPIC fuel fabrication are the development of the manufacturing technology to produce pellets with high density, the development of remote fabrication equipment to be used in highly shielded hot cells and the handling of radioactive materials during processing. The powder treatment process, called OREOX, of PWR spent fuel material has been developed to manufacture the DUPIC pellets in accordance with current CANDU fuel specifications. Based on the pelletizing technology developed using simulated spent fuel and the developed fabrication equipment, the experimental fabrication of DUPIC fuels has been performed at KAERI from January 2000.

A series of irradiation tests using the HANARO research reactor at KAERI are planned to be carried out to verify the performance of DUPIC fuels. In addition, theoretical analysis of DUPIC fuel behaviors in the commercial CANDU reactors is under way to check the compatibility of DUPIC fuels in terms of reactor physics, safety and handling.

Introduction

Since the first commercial operation of Kori-1 Nuclear Power Plant in 1978, Korea is currently operating 14 nuclear units including 11 PWRs(Pressurized Water Reactor) and 3 CANDUs(CANadian Deuterium Uranium). Nuclear power is presently supplying about 35 percent of total electricity generation in Korea and the total nuclear capacity is 12,016 MWe as of March 1999. Five PWRs and one CANDU are under construction, and eight more nuclear power plants are planned for completion by 2010 as shown in Table 1.

In order to maintain continuous growth of the nuclear power industry in Korea, several issues such as safety of nuclear reactor operation, spent nuclear fuel management, and non-proliferation concerns, etc. should be kept in mind. Nuclear energy does produce highly radioactive spent fuels, which contain not only fission products, but also unused uranium and newly generated plutonium.[1] For this reason spent nuclear fuel has been regarded both as a radioactive waste to be buried, and as a valuable source of recoverable fuel. However, in the latter option, separation of the sensitive materials, plutonium in particular, has been a constant point of political concern for the possibility of diversion.

Taking advantage of the Korean nuclear reactor strategy of having both light water reactors(PWR) and heavy water reactors(CANDU) for electricity generation, DUPIC nuclear fuel cycle concept has been suggested as one of the solutions of spent fuel management, while improving the utilization of uranium resources in a proliferation-resistant way.

The DUPIC Alternative

The DUPIC fuel cycle can be an alternative to the conventional spent fuel management options of direct disposal or plutonium recycling using wet reprocessing. The PWR spent fuel can be burned again in CANDU reactors by direct refabrication of CANDU-compatible DUPIC fuel. The DUPIC fuels can be fabricated by only mechanical and thermal processes without any separation of sensitive nuclear materials even fission products, because the remnant fissile content in the PWR spent fuel is high enough to be reused in CANDU reactors.

By utilizing the DUPIC fuel cycle, three advantages can be expected such as no need for PWR spent fuel disposal, the saving of natural uranium resources for the fabrication of CANDU fuel and the increase of CANDU fuel burnup by utilizing the DUPIC fuel. It is assessed that there will be a 30 percent savings in uranium resources and 70 percent reduction in the amount of spent fuel when comparing the DUPIC cycle with the once-through fuel cycle for the production of the same amount of electricity.

However, challenges for the utilization of the DUPIC fuel concept are the development of the pelletizing technology to produce pellets with high density, the development of remote fabrication equipment to be used in highly shielded hot cells and handling of radioactive materials. Also the compatibility of the DUPIC fuel in terms of reactor physics, impacts on the safety system in reactor, and remote fuel handling need to be evaluated.

Compatibility of DUPIC Fuel with Existing CANDU System

A premise of the DUPIC fuel development is to make maximum use of the existing CANDU reactor design. This approach has led to a number of compatibility studies of DUPIC fuel with the existing CANDU system. The inherent features of the CANDU reactor result in an unsurpassed degree of fuel cycle flexibility, enabling DUPIC fuel to be utilized safely and economically in existing reactors. Evaluation in terms of neutronics, thermal hydraulics, reactor safety, radiation protection, and fuel handling are required.

For the mechanical compatibility, DUPIC fuel design will be modeled based on the current CANDU designs for 37-element or CANFLEX(CANdu FLEXible) fuel bundles. With such an approach, no particular problems would arise in mechanical compatibility with the existing CANDU, except in the handling of radioactive DUPIC fuel outside the core. However, feasibility studies have revealed the DUPIC fuel could be loaded into the fuel channel by reversing the path of CANDU spent fuel handling from the storage pool.

For the nuclear and associated compatibilities, a variety of technical topics are being studied such as the refueling scheme, reactivity control, operational margin, suppression of LOCA and control of fuel composition, etc. Even though the DUPIC fuel contains about 1.5 wt % fissile materials, which is more than twice that of natural uranium, the excess reactivity of DUPIC fuel can be managed by adopting a 2-bundle shift refueling scheme due to the on-power refueling in a CANDU reactor. In this way, the maximum channel and bundle power and channel power peaking factor can be maintained lower or similar to those of a natural uranium core.

Due to the higher fissile content and the presence of plutonium and neutron absorbing fission products, the worth of reactivity device changes. However, it has been shown that the reactivity worth of the zone controller units and the adjuster rods are sufficient to maintain their functions. The shutoff rods and poison injection system also possess sufficient reactivity for reactor shutdown.

The existence of plutonium in DUPIC fuel causes more rapid response in a postulated positive reactivity insertion, such as in a loss of coolant accident. Transient and safety analyses have shown that the power pulse in a representative LOCA scenario can be reduced sufficiently by the addition of a small amount of neutron absorber in the center rod of a DUPIC fuel bundle.

The composition of DUPIC fuel is tightly controlled; the fissile content is adjusted with fresh uranium. Moreover, the diverse variation in the composition of spent PWR fuel can also be used as an abundant source of material for fuel composition homogenization by mixing spent PWR fuel of low and high fissile content. By doing this, the uncertainties in fuel composition and core performance parameters are reduced appreciably.

DUPIC Fuel Fabrication Process

As the name implies, the DUPIC fabrication processes involve the direct refabrication of PWR spent fuel into CANDU fuel using only thermal and mechanical processes. The oxidation and reduction process called as OREOX(Oxidation and REduction of OXide fuel) was chosen as the most promising method for the fabrication of DUPIC fuel with high density and homogeneity. The spent fuel material is recovered from the PWR spent fuel by disassembling and decladding using mechanical and thermal processes. The powder preparation process called OREOX is considered as the most critical process for producing resinterable powder feedstock. During the oxidation and reduction at high temperature, the fuel materials are subject to phase transformation accompanied with volume changes. This volume change pulverizes the powder and develops more micro-crack to increase the sinterability of the powder.

Once the resinterable powder is prepared, the pellet and rod manufacturing processes are almost same as the conventional powder/pellet route in CANDU fuel fabrication. The fabrication flow is illustrated in Fig. 1. Since all the fabrication processes are strongly radioactive, as it contains all the stable fission products, the development of fabrication equipment which will be remotely operated and maintained in the shielded hot cells is another challenge for the success of DUPIC fuel development.[2]

Proliferation Resistance and Nuclear Material Safeguards

One of the important DUPIC features is its excellent proliferation resistance, since no fissile material is separated in the DUPIC fuel fabrication process. Moreover, DUPIC fuel is refabricated directly from highly radioactive PWR spent fuel, and therefore access to the sensitive material is extremely difficult.

However, nuclear materials safeguards remain as an essential element of the DUPIC development, in particular, nuclear materials accountability and containment and surveillance. The heavy shielding enclosure required for the DUPIC fuel processes naturally complies with such protective containment and facilitates the material accountability at key measurement points.

A nuclear material accounting system for DUPIC safeguards such as DSNC(DUPIC Safeguards Neutron Counter) and ICS(Intelligent Containment and Surveillance) is being developed in cooperation with the USA. DSNC is a well-type neutron coincidence counter and can measure the amount of curium in the fuel. Pu and U contents are inferred from the amount of curium. The proportionality between the coincidence neutron counter rate, burn-up and curium-244 content has been verified experimentally. It has been proved that DSNC is a reliable technology for use in DUPIC process safeguards.

In structuring a safeguards system for a DUPIC facility, it is important to continuously monitor the flow of fuel materials in the hot cells. In order to provide an unattended, continuous, integrated surveillance system, a study on the effectiveness of a time-synchronized radiation and image monitoring system in the DUPIC process has been performed. In the system development, particular effort is directed at digital analysis of events by incorporating a neural network mechanism to selectively draw a conclusion on only significant events throughout the monitoring period. Demonstration of the system was done in 1998 by integrating the video and NDA radiation sensors in a common time dimension through image processing and designing a computer interface for the neutron counting sensor.

DUPIC Development Program in KAERI

A comprehensive research and development program is being implemented at KAERI to demonstrate the DUPIC fuel cycle concept. In the earlier assessment, a broad feasibility study was carried out to identify any feasibility issues of a fundamental nature during 1991 to 1993. The basic compatibility and safeguardability has been confirmed, and the OREOX process was selected as the most promising fabrication method for the DUPIC fuel development.

In the following experimental verification program of DUPIC fuel, which is currently being conducted in full momentum, wide research topics including compatibility assessment, safeguards development, irradiation technique improvement and technology for the remote fabrication of DUPIC fuel are under way. At KAERI, adequate facilities are already ready for available for the necessary works and they are suitably rigged in most parts of the system. Fuel rods can be segmented in PIEF(Post-Irradiation Examination Facility) and transported in a shielded cast to the nearby IMEF(Irradiated Material Examination Facility) hot cell. The major experiment works for DUPIC fuel fabrication tests are performed in the M6 cell of the IMEF, which has ten windows. Most of the process equipment was developed and installed. Several DUPIC pellets were made by using developed equipment. The fuel irradiation capsule was also developed. The preliminary irradiation test was done by using the developed capsule and simulated DUPIC pellets. By the end of March 2000, DUPIC mini-element for the irradiation test will be fabricated and the first irradiation test will start at the research reactor, HANARO, in KAERI.[3] The outline of the DUPIC fuel development program is shown in Figure 2.

Summary

The DUPIC cycle offers multi-faceted benefits, such as security of supply and protection from uranium and enrichment price changes. Security of supply is assured by the existing inventory of PWR spent fuel. The development of PWR-CANDU fuel cycle, such as DUPIC, transforms this inventory from a waste-disposal cost into a valuable energy resource.

Anticipated benefits of the DUPIC synergism are : (1) saving of natural uranium for CANDU fuel fabrication due to the reuse of the PWR spent fuel, (2) removal of PWR spent fuel, which has been transformed to DUPIC fuel, (3) reduction of spent fuel arising from CANDU due to the increase of the CANDU burnup, (4) environmental benefits due to the transmutation effect of burning again PWR spent fuel in CANDU reactor.

Besides the DUPIC synergism can produce benefits to such countries having both LWR(Light Water Reactor) and HWR(Heavy Water Reactor). Also, it is conceivable to extend the benefits of DUPIC to an international dimension by linking one country having PWRs to another having CANDUs.

Acknowledgements

This work has been carried out under the Nuclear Research and Development Program of Korea Ministry of Science and Technology.

References

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Table 1. Status of Korean Nuclear Power Plants.

Nuclear Power Plant	Location	Reactor Type	Capacity (Mwe)	Reactor Supplier	Start of Operation
Kori-1	Kyungnam	PWR	587	USA(W)	1978. 4
Kori-2	Kyungnam	PWR	650	USA(W)	1983. 7
Kori-3	Kyungnam	PWR	950	USA(W)	1985. 9
Kori-4	Kyungnam	PWR	950	USA(W)	1986. 4
Younggwang-1	Chunnam	PWR	950	USA(W)	1986. 8
Younggwang-2	Chunnam	PWR	950	USA(W)	1987. 6
Younggwang-3	Chunnam	PWR	1000	Korea(KHIC)	1995. 3
Younggwang-4	Chunnam	PWR	1000	Korea(KHIC)	1996. 3
Younggwang-5	Chunnam	PWR	1000	Korea(KHIC)	(2001. 12)
Younggwang-6	Chunnam	PWR	1000	Korea(KHIC)	(2002. 12)
Uljin-1	Kyungbuk	PWR	950	France	1988. 9
Uljin-2	Kyungbuk	PWR	950	France	1998. 9
Uljin-3	Kyungbuk	PWR	1000	Korea(KHIC)	1998. 9
Uljin-4	Kyungbuk	PWR	1000	Korea(KHIC)	(1999. 6)
Uljin-5	Kyungbuk	PWR	1000	Korea(KHIC)	(2004. 2)
Uljin-6	Kyungbuk	PWR	1000	Korea(KHIC)	(2005. 2)
Wolsung-1	Kyungnam	CANDU	679	Canada(AECL)	1983. 4
Wolsung-2	Kyungnam	CANDU	700	Canada(AECL)	1997. 6
Wolsung-3	Kyungnam	CANDU	700	Canada(AECL)	1998. 7
Wolsung-4	Kyungnam	CANDU	700	Canada(AECL)	(1999. 6)

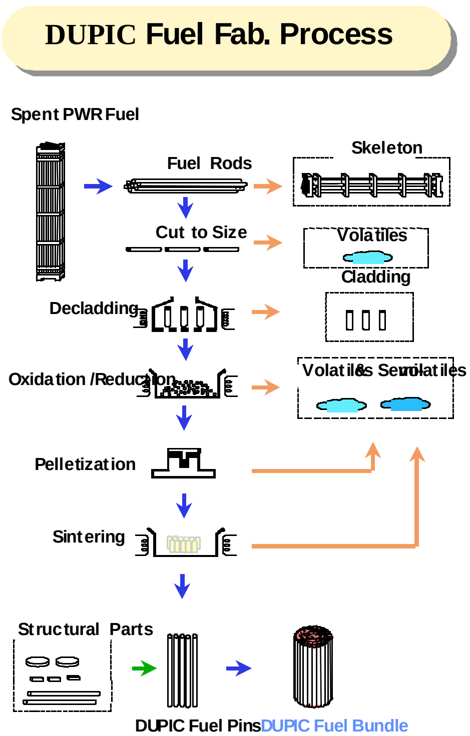

Figure 1. DUPIC Fuel Fabrication Process.

Figure 2. DUPIC Fuel Development Program in Korea.

Work Area	Phase I	Phase II								Phase III
	91~'93	94	95	96	97	98	99	00	01	02~'06
Feasibility Study										
Experimental Verification of DUPIC Performance										
- Compatibility assessment										
- Safety assessment										
- Manufacturing technology development										
- Fabrication of pellets and elements										
- Irradiation tests of pellets and mini-elements										
- Safeguards technology development										
Demonstration of DUPIC Fuel										
- Fabrication of DUPIC bundles										
- Demonstration of DUPIC fuel										